AN1657
APPLICATION NOTE

SMPS FOR CRT MONITORS WITH THE L6565

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This note shows and discusses a couple of designs of a 90W wide-range-mains SMPS for CRT monitor based on the QR controller L6565. The first design refers to a low-cost SMPS that meets current EnergyStar® requirements on OFF-mode consumption (Pin<2W). The second design is an evolution of the first one so as to be compliant with IEA's "1W initiative". Both have been realized and tested on the bench. The result of their evaluation is presented along with some significant waveforms.

Design Specification

The typical electrical specification of an SMPS of a 17" CRT monitor for PC is summarized in table 1. Two goals concerning the off-mode consumption of the SMPS have been set: the first one is to meet the present EnergyStar® requirements, which envisage less than 2W absorbed from the mains; the second more ambitious goal is to comply with IEA's "1W initiative" as well as to be eligible for GEEA label. Both voluntary standards require to achieve a power consumption below 1W.

Table 1. 90W SMPS for CRT monitor: electrical specification

Input Voltage Range (Vin)		88 to 264 Vac
Mains Frequency (f_L)		50/60 Hz
Maximum Output Power (Pout)		92 W
Outputs	Horizontal Deflection	Vout = 200V ± 3%
		Iout = 0.33A
		Full load ripple = 1%
	Video Amplifier	Vout = 80V ± 5%
		Iout = 0.13A
		Full load ripple = 1%
	Vertical Deflection	Vout = ± 15V ± 10%
		Iout = 0.33 A
		Full load ripple = 1%
	Heater	Vout = 6.5V ± 10%
		Iout = 0.6A
		Full load ripple = 2%
	Micro	Vout = 5.0V ± 2%
		Iout = 0.05A
		Full load ripple < 1%
Minimum Switching Frequency in Normal Mode (f_{MIN}, @ Vin = 100 V_{DC}, full load)		25 kHz
Target Efficiency (Vin =88 to 264 Vac, full load) (η)		> 85%
Suspend-Mode Input Power (Vin = 88 to 264 Vac)		<15 W
OFF-Mode Input Power (@Pout = 125 mW on 5V output, Vin = 88 to 264 Vac)		< 2W (EnergyStar®)
		< 1W (IEA, GEEA)

QR approach and the L6565

The SMPS will be realized with a Quasi-resonant (QR) flyback converter based on the L6565, a control IC specifically designed to handle such kind of converters. Referring to [1] and [2] for a detailed description of the device and the topology, it is here worthwhile reminding that QR operation implies that the transformer always works close to the boundary between continuous and discontinuous conduction mode and thereby at a switching frequency that depends on the input voltage and the output current. The ripple across the input bulk capacitor modulates the switching frequency in itself. This characteristic, besides being advantageous in terms of EMI emissions (it spreads the spectrum), makes it more difficult to see the noise on the screen. Furthermore, with QR operation MOSFET's turn-on occurs with zero or minimum drain voltage, which minimizes the switching noise generated. Finally, since the converter always operates in discontinuous conduction mode the reverse recovery characteristics of the secondary rectifiers are not invoked, which goes in favor of a "quiet" operation too.

The above-mentioned characteristics, coupled with the high degree of safety under short circuit conditions inherent in its operation, make QR approach ideal for noise-sensitive applications as monitors are.

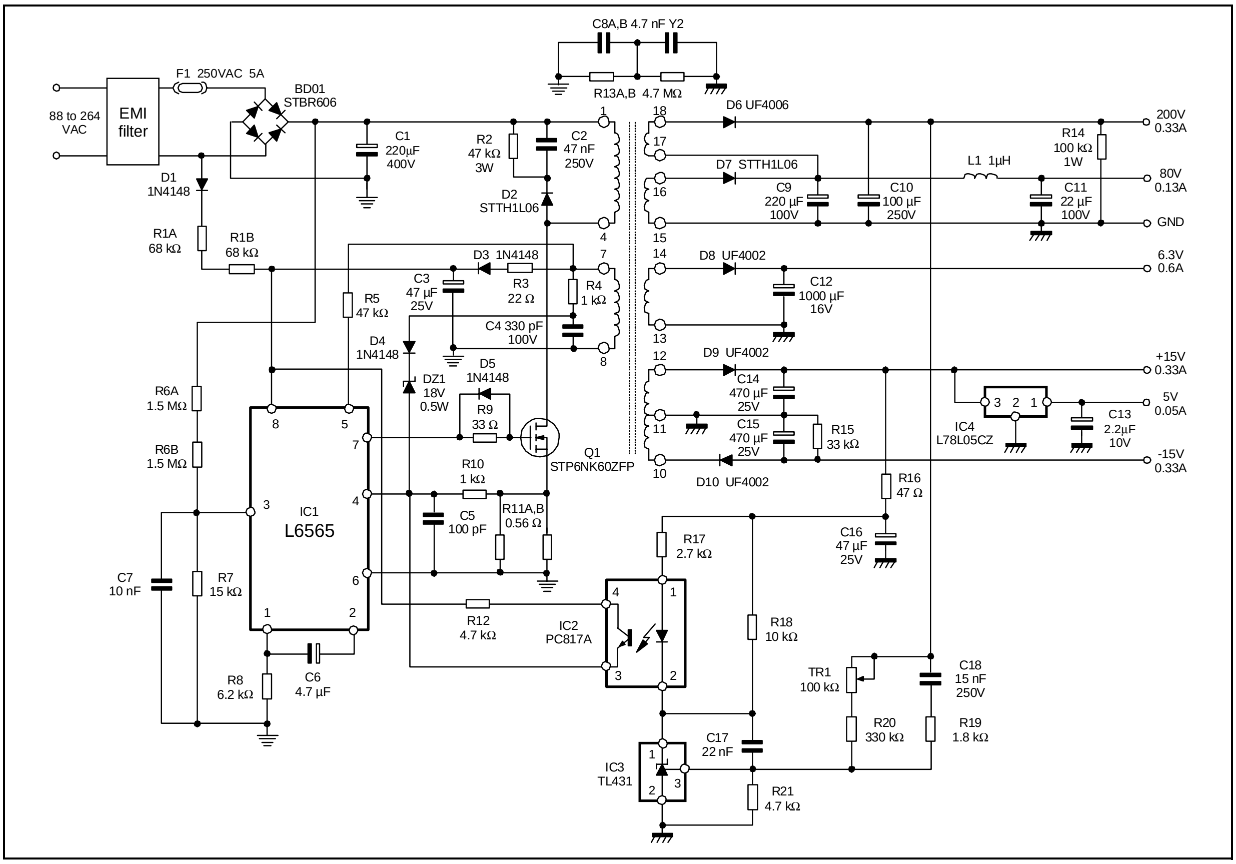
The L6565 is an excellent low-cost solution to implement reliable and energy-efficient QR flyback converters both under maximum and minimum load conditions. The internal functions of the IC (frequency foldback and burst-mode operation at light load) as well as its inherent low consumption (less than 70 µA start-up current and less than 3.5 mA quiescent current) make designer's life easier when they face the challenging tasks of meeting energy-saving requirements.

Additionally, the L6565 offers a safety feature (device disable upon secondary rectifier short circuit) that can be fruitfully put to use in the present context to achieve an ultra-low consumption at light load. To protect the converter in the event of such failure, an internal comparator senses the voltage on the current sense pin of the IC and disables the gate driver if this voltage exceeds 2V. To re-enable the driver, the supply voltage of the IC must fall below the UVLO threshold and then exceed again the start-up threshold.

EnergyStar® compliant design

The first proposed schematic is shown in figure 1. Only its more significant features will be commented, please refer to [2] for the standard characteristics of an L6565-based QR flyback.

Figure 1. L6565-based, EnergyStar® compliant, 90W SMPS for CRT monitor: electrical schematic



The converter is started up by R1A, R1B and the diode D1 that draw some current from the AC side of the bridge rectifier. This inexpensive circuit wakes up the system in less then 3s @ 88 VAC and contributes to light load losses with 240 mW @ 264 VAC. Despite this dummy consumption it is anyway possible to meet the target of less than 2W input consumption thanks to the favorable features of the L6565. Supplying the IC from the AC side of the bridge helps reduce the power consumption on the start-up resistors and eliminates any chance of spurious restarts at converter's power down.

R6A and B along with R7 correct the overcurrent setpoint so as to minimize the power capability change of the converter over the entire input voltage range. C7 filters out any noise that might be coupled to the pin.

R8 and C6 provide soft-start. At start-up C6 is charged by the output of the L6565 E/A (pin 2) with a current defined by 2.5 / R8 and the E/A works temporarily closed-loop. As the E/A saturates high there is no more current through C6, the loop opens, the voltage on pin 1 (E/A input) goes to zero and pin 2 stays high at about 6V. When the L6565 turns off (because its supply voltage Vcc goes below the UVLO threshold) the capacitor is discharged internally in few milliseconds - because the impedance of the pins becomes low - in this way ensuring a correct soft-start even when the L6565 is continuously restarted (e.g. in case of overload or short circuit).

Output voltage regulation is done with a TL431+optocoupler arrangement on the secondary side and the information is fed back to the current sense pin (#4) of the L6565. Regulation is thus performed by modulating the voltage offset generated by the phototransistor current on R10. C5 adds a small filtering effect to increase noise immunity. This feedback arrangement helps reduce the load of the self-supply system (winding 7-8, D3, R3, C3). In fact with the usual arrangement, where the phototransistor sinks current from pin 2 (with pin 1 grounded), the regulation current, typically 3 mA at light load, adds up to the operating current of the IC. With this circuit, to create about 1V offset, which is required at light load, the phototransistor needs to draw only 1 mA. This load reduction will counteract the natural decay of the self-supply voltage when the converter is lightly loaded. Please note that with this technique the ZCD masking time of the L6565 (refer to [2] for details) is fixed at 3.5 µs.

The circuit made up of R4, C4, D4 and DZ1 provides overvoltage protection in case of failure of the feedback loop. R4 and C4 smooth the waveform generated by the self-supply winding to suppress the leading edge spike that could mislead the circuit. During MOSFET's off-time the winding generates a voltage proportional to the output voltage. Thus, if the feedback loop opens (e.g. the optocoupler fails), which causes the output voltage to rise above the regulated value, the voltage provided by R4, C4 will increase as well. DZ1 will be turned on and inject an additional offset on the current sense pin after MOSFET's turn off. As the voltage on the pin reaches 2V an internal comparator will be triggered, the L6565 will shut down and the converter will be stopped until L6565's Vcc voltage, after falling below the UVLO threshold, goes again above the start-up threshold. This may take some hundreds milliseconds, then the system will work in a continuous restart mode, the energy throughput will be very low and the output voltage will not reach dangerous values.

Table 2. L6565-based 90W SMPS for CRT monitor: transformer specification

Core	Philips ETD44, 3C85 Material				
Bobbin	Horizontal mounting, 18 pins				
Air gap	≈ 1 mm for an inductance 1-4 of 380 µH				
Leakage inductance	< 10 µH				
Windings Spec & Build	Winding	Wire	S-F	Turns	Notes
	Pri1	4xAWG29	2-4	19	Pin 4 is cut for safety
	Sec1 (200V)	AWG25	17-18	48	
	Sec2 (80V)	AWG25	15-16	32	
	Sec3 (6.5V)	AWG25	13-14	3	Evenly spaced
	Sec4 (+15V)	AWG25	11-12	6	Bifilar with Sec5
	Sec5 (-15V)	AWG26	10-11	6	Bifilar with Sec4
	Pri2	4xAWG29	1-2	19	
	Aux (+15V)	AWG29	8-7	7	Evenly spaced

The linear regulator that supplies the 5V line for the µP takes its input from the +15V line. Using the 6.5V line would improve efficiency (especially in OFF-mode) even further. To do so, however, an LDO (low dropout) regulator is needed (with the L7805 at least 2V dropout must be ensured), which is slightly more expensive, and the transformer must supply a sufficient voltage (5V plus the dropout and the tolerances) under all operating conditions. Actually, in Suspend mode with the heater still supplied the 6.5V drops at 5.5V, which forces the use of the +15V line. Either with a better transformer construction - so that the 6.5V line never falls below, say, 6V or turning off the heater during Suspend mode, an LDO regulator could provide 5V powered by the 6.5V line, thus reducing the converter actual load by about 150 mW.

There is no special circuit that handles the OFF-mode operation: simply, when the monitor enters OFF-mode the loads drop to negligible values on all of the outputs except the 5V one that must still supply the µP governing monitor operation. In these conditions µP's consumption is estimated at 25 mA max. As a result, the L6565 will enter its natural burst-mode operation, where a series of few switching cycles are repeated at the frequency of the internal starter or at a submultiple of its. The consumption measurements under these operating conditions are shown in table 4 in the "Experimental results" section.

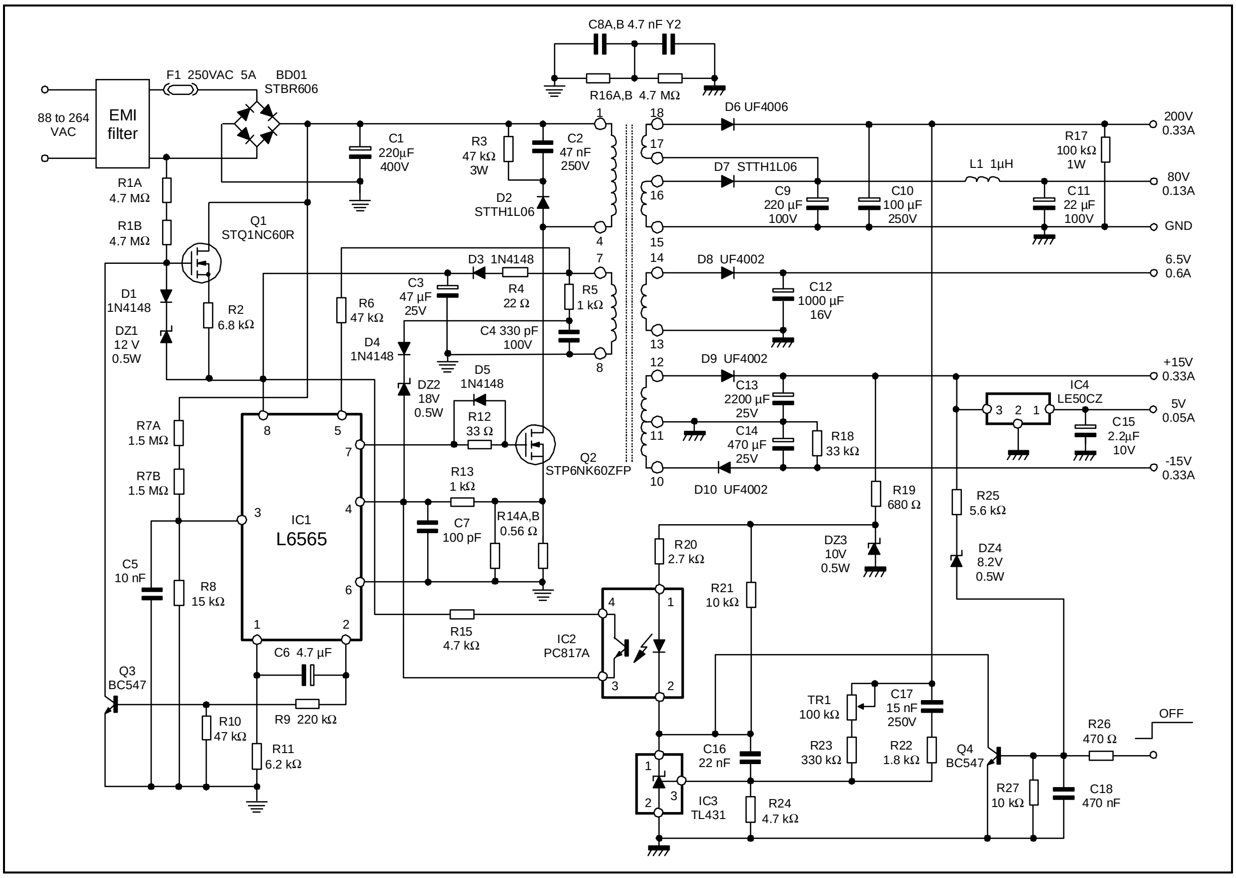
"1W Initiative" compliant design

To make such design the starting point will be the EnergyStar® compliant circuit, which a circuitry dedicated to handle the OFF-mode will be added to. Besides the additional circuitry, minimum adaptations in the power section and some changes in the control circuit will be required. Figure 2 shows the resulting schematic.

Conceptually, the way OFF-mode is handled consists of forcing the L6565 to work in a very low frequency controlled burst-mode (continuous restart), so as to cut all frequency-related losses. To see how this is achieved practically it is worth examining the schematic of figure 2, specifically looking at the new and modified parts as compared to the schematic of figure 1.

Starting from the primary side, the major addition is the high-voltage active start-up circuit (R1A, R1B, R2, D1,DZ1 and Q1) along with the associated network (R9, R10, Q3) to turn it off when the converter is running. This addition has a not negligible impact on the part count and the total cost but is essential.

Figure 2. L6565-based, "1W Initiative" compliant, 90W SMPS for CRT monitor: electrical schematic



The importance of the circuit lies not only in the reduction of the associated losses from the 240 mW of the resistive start-up to less than 10 mW, but also in the fact that, arranged as a current source like in the schematic of figure 2, it provides constant wake-up and restart times for the converter, regardless of the input AC voltage. The benefits resulting from that will be clearer after discussing how the system handles OFF-mode operation. The current sourced by the generator and that charges the V_{CC} capacitor C3 is:

$$I_{CH} = \frac{V_Z + V_F - V_{th}}{R2},$$

where V_Z is the zener voltage of DZ1, V_F the forward drop across D1 and V_{th} the threshold voltage of Q1. With an appropriate selection of V_Z it is possible to compensate the temperature drift of both V_F (≈ -2 mV/°C) and Vth (≈ -7 mV/°C). Experience shows that zener diodes with V_Z =12V have a temperature coefficient around +10 mV/°C, thus one of them will be selected.

With this circuit, neglecting the start-up current absorbed by the L6565, which is typically two orders of magnitude smaller, the wake-up time is defined by R2, C3 and the turn-on threshold (V_{CCOn}) of the L6565:

$$T_{wake-up} \approx \frac{C3}{I_{CH}} V_{CCOn},$$

whereas the restart time, that is the time needed for Vcc to go from the UVLO threshold (V_{CCOff}) to V_{CCOn} during a continuous restart, depends on the V_{CC} hysteresis ($V_{CCHys} = V_{CCOn} - V_{CCOn}$) of the L6565:

$$T_{Restart} \approx \frac{C3}{I_{CH}} V_{CCHys}.$$

The circuit that is actually responsible for handling OFF-mode operation is on the secondary side and is the network comprising R25 to R27, C18, DZ4 and Q4. To adapt the existent circuit to the new operation, R19 (R16 in the schematic of fig. 1) has been increased to 680Ω and the capacitor C13 has been replaced by the zener diode DZ3. The bulk capacitor C13 on the +15V line has been increased from 470 to 2200µF and the L7805 replaced by an LE50CZ.

During normal operation a logic signal (open collector) governed by the µP keeps the OFF input low, so that Q4 is always off and the OFF-mode circuit is disabled. When the monitor is to enter OFF-mode the µP acts so that the loads of all the outputs are cut off, then it reduces its own consumption and opens the pull-down that was grounding the OFF input. Q4 is immediately turned on because the voltage on the +15V is already higher than threshold (V_T) defined by DZ4, R25 and R27. Q4 will then draw a relatively large current from the photodiode, limited by R19+R20 (that is why C13 has been replaced by DZ3: this will still give a high frequency pole to the output-to-control transfer function but will keep the current through the photodiode under control as Q4 is turned on).

As a result there will be quite a large current in the phototransistor too, which will bring the voltage on the current sense pin above the 2V threshold that shuts down the driver of the L6565 and stops PWM activity. The IC, however, remains active and pin 2 stays high, thus keeping the start-up generator off as long as Vcc - which is decaying because of the quiescent consumption of the IC and the phototransistor current - is above V_{CCOff}. As $V_{CC} = V_{CCOff}$ the IC turns off, pin 2 goes low and the start-up generator is turned on again.

This is the most critical moment: since the output voltage starts from about 15V and needs to decay below V_T before Q4 turns off, the phototransistor will keep on sinking quite a large current even after the start-up generator is enabled. As a result, V_{CC} will be pulled well below V_{CCOff}. The start-up generator will take a time longer than $T_{Restart}$ to bring V_{CC} back to V_{CCOn} and restart PWM activity. On the secondary side, as the L6565 stops switching the voltage on C13 starts to decay slowly and goes on like that as long as the L6565 does not switch. Even during this time the voltage on C13 must not go below the minimum value that correctly supplies the linear regulator. To have maximum headroom the LE50CZ has been used, which features less than 0.5V dropout. Besides, this part has lower quiescent current and the low dropout allows keeping a lower average input voltage, which helps reduce the actual load on the converter.

As PWM restarts, the voltage on C13 quickly builds up and reaches V_T in few milliseconds, which turns on Q4 again restarting another cycle. C18 filters switching noise and allows a clean Q4 turn-on. This time the phototransistor current will drop to zero before Vcc falls below V_{ccOff} and there will be no V_{CC} undershoot.

Under steady-state operation the L6565 will be then shortly activated with a repetition rate T_{Rep} essentially given by T_{Decay} + $T_{Restart}$, where T_{Decay} is the time that V_{CC} takes to span V_{CC} hysteresis downward:

$$T_{Decay} \approx \frac{C3}{I_q} V_{CCHys},$$

and I_q is the quiescent consumption of the L6565. The input of the linear regulator is a sawtooth going from a peak $\approx V_T$ to a valley that depends on T_{Rep}, C13 and the input current to the LE50CZ. Also Vcc is a sawtooth going up and down from V_{CCOn} to V_{CCOff} .

When the monitor is to resume its normal operation the OFF input will be grounded thus inhibiting Q4 and disabling the OFF-mode circuit. However, the L6565 will be able to respond only when it is active. Under the worst-case conditions, that is the OFF input is grounded just after the IC has been shut down, the L6565 will be responsive only after a time T_{Rep}. The power management software must take this into account, re-enabling the loads on all of the outputs with a delay not shorter than T_{Rep} after grounding the OFF input.

Experimental results

In the following tables the results of some bench evaluations are summarized. Some waveforms at full load and off-mode under different line conditions are shown for user's reference, with some stress on the OFF-mode management of the "1W initiative" compliant design.

As to the full-load performance there is no significant difference between the two designs presented: table 3 is common to both. Same applies to table 4 that shows the consumption during Suspend-mode operation, a particular low-consumption mode envisaged by VESA standards. No special action is taken to keep the consumption below the limit (Pin < 15W): the converter can comfortably fulfill this requirement.

Table 3. L6565-based, 90W SMPS for CRT monitor: line regulation and full load efficiency

V_{AC} [V]	88	110	132	176	220	264
Pin [W]	103.9	101.0	99.6	98.4	98.4	98.6
Vout [V]	199.90	199.87	199.84	199.83	199.86	199.82
	79.45	79.40	79.39	79.37	79.38	79.39
	14.12	14.13	14,14	14.14	14.16	14.16
	-14.20	-14.20	-14.21	-14.21	-14.22	-14.22
	6.58	6.60	6.62	6.63	6.64	6.65
Pout [W]	90.59	90.61	90.63	90.64	90.69	90.69
η [%]	87.2	89.7	91.0	92.1	92.2	92.0
Load conditions: 200V: 0.33A; 80V: 0.13A; ±15V: 80 Ω; 6.5V: 10Ω; 5V: 0.05A						

Table 4. L6565-based, 90W SMPS for CRT monitor: Suspend-mode consumption

V_{AC} [V]	88	110	132	176	220	264
Pin [W]	12.6	12.9	13.3	13.3	13.4	13.6
Load conditions: 200V: 0.005A, 80V: 0.065A; ±15V = open; 6.5V: 10Ω (heater on); 5V: 0.025A. Pout ≈ 9.3W						
Pin [W]	8.3	8.3	8.5	8.5	8.6	8.7
Load conditions: 200V: 0.005A, 80V: 0.065A; ±15V = 6.5V = open (heater off); 5V: 0.025A (LDO regulator supplied from 6.5V line). Pout ≈ 6.3W. Note: a) Applicable to EnergyStar® compliant design only. b) Efficiency improvement is due to onset of L6565 burst-mode operation.						

Table 5. L6565-based, EnergyStar® compliant design: OFF-mode consumption

V_{AC} [V]	88	110	132	176	220	264
Pin [W]	1.4	1.4	1.4	1.4	1.5	1.6
Load conditions: 200V = 80V = ±15V = 6.5V = open; 5V: 0.025A. Pout = 0.125W						
Pin [W]	1.2	1.2	1.2	1.2	1.3	1.4
Load conditions: 200V = 80V = ±15V = 6.5V = open; 5V: 0.025A (LDO regulator supplied from 6.5V line)						

Table 6. L6565-based, "1W Iniziative" compliant design: OFF-mode consumption

V_{AC} [V]	88	110	132	176	220	264
Pin [W]	0.25	0.31	0.38	0.49	0.62	0.75
Load conditions: 200V = 80V = ±15V = 6.5V = open; 5V: 0.025A. Pout = 0.125W						

Figure 3. Line filter (not tested for EMI compliance) used during prototype bench evaluation

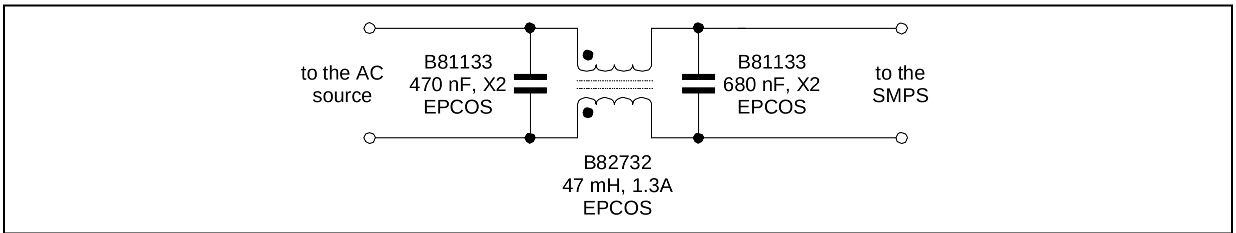


Figure 4. L6565-based, 90W SMPS for CRT monitor: Full load, V_{in}=100 VDC (left), V_{in}=380 VDC (right)

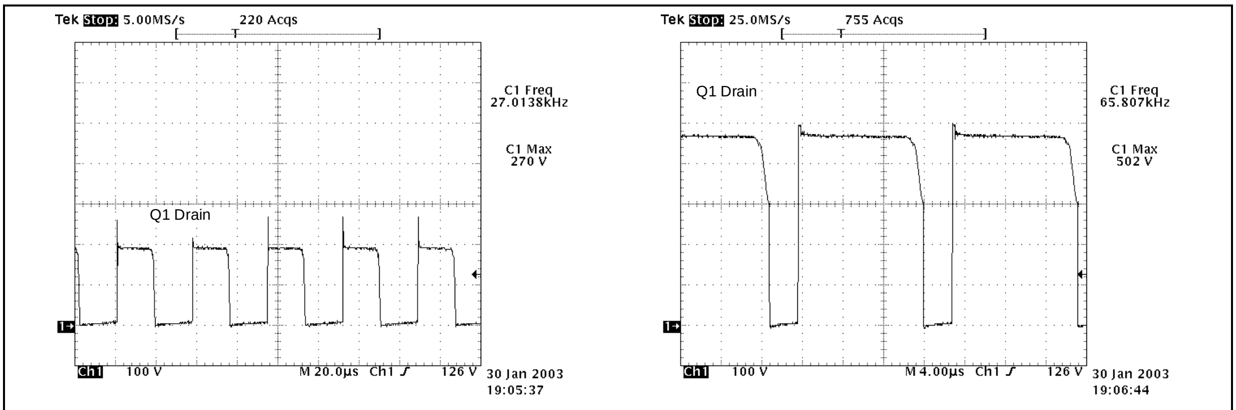


Figure 5. L6565-based, 90W SMPS for CRT monitor: Open feedback and OVP, main waveforms

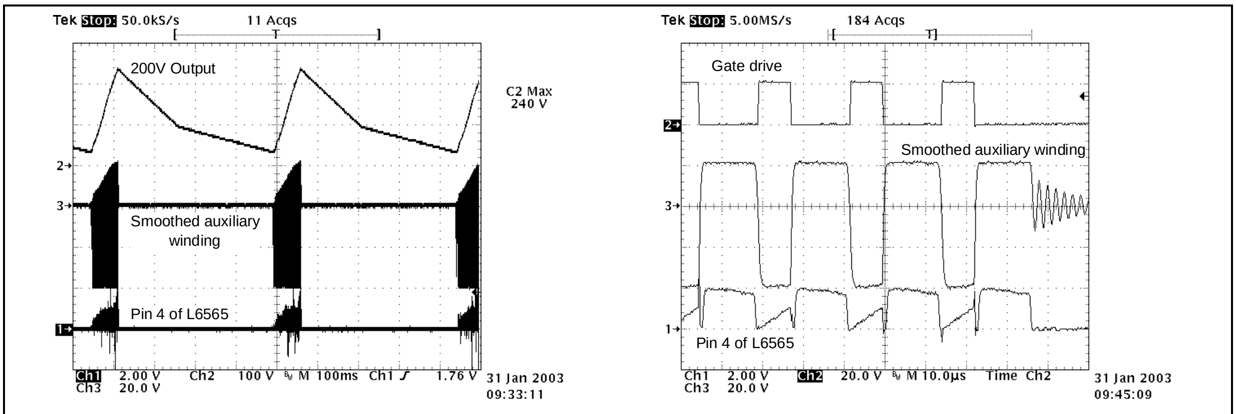


Figure 6. L6565-based, EnergyStar® design: OFF-mode, Vin = 100 VDC (left), Vin = 380 VDC (right)

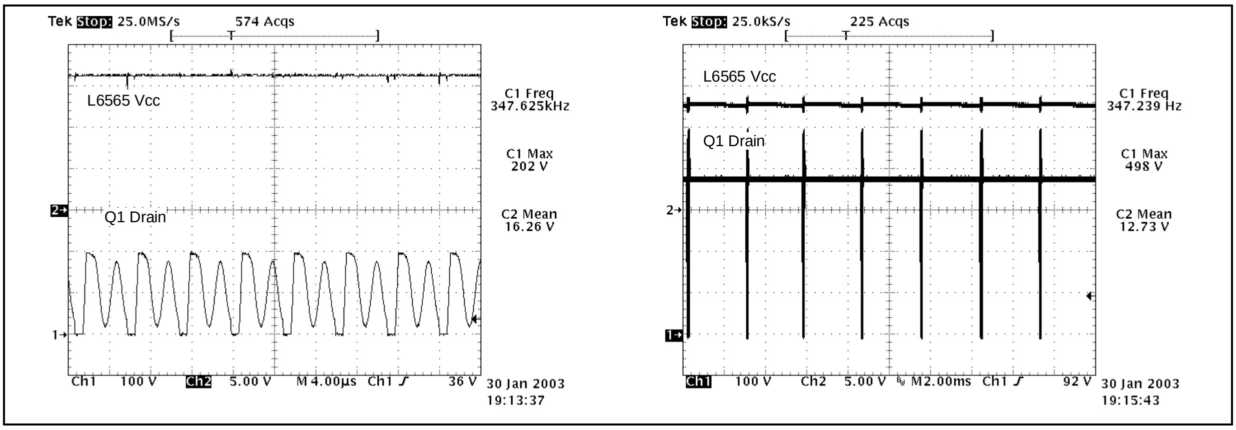


Figure 7. L6565-based, "1W Initiative" compliant design: OFF-mode main waveforms

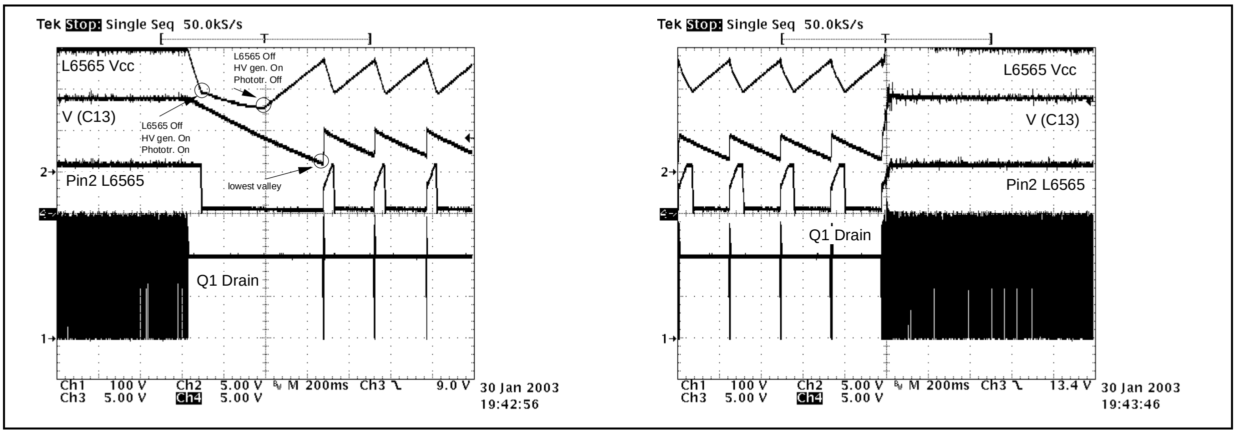
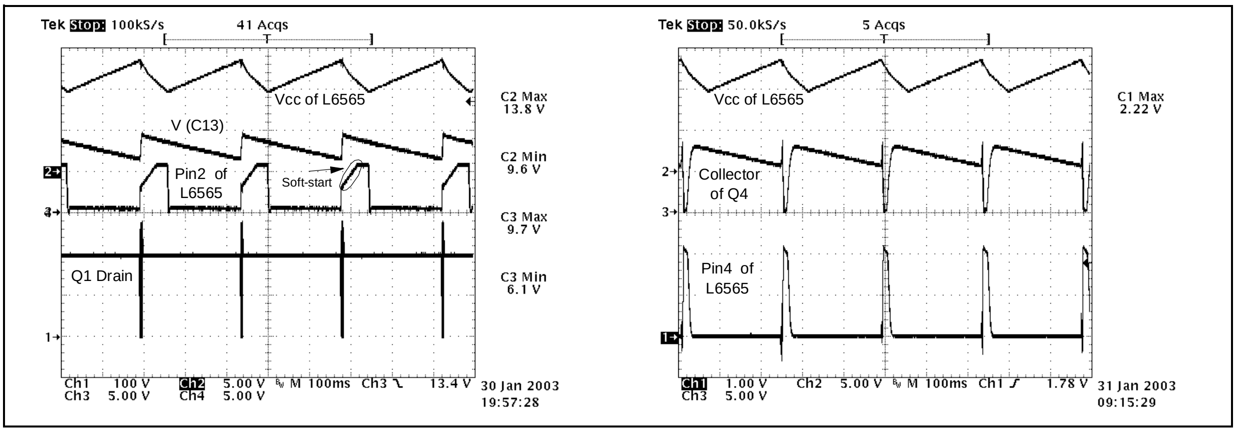


Figure 8. L6565-based, "1W Initiative" compliant design: entering (left) and exiting (right) OFF-mode



Conclusions

Two designs of a CRT monitor SMPS based on the QR controller L6565 have been realized and the results of their bench evaluation have been presented. The first one is a low-cost design able to meet current EnergyStar® requirements on OFF-mode consumption (Pin < 2W). The second design, at the price of a slight part count and cost increase, meets the target Pin <1W, which makes it compliant with IEA's "1W initiative" as well as eligible for GEEA label.

REFERENCES AND RELATED DOCUMENTATION

[1] "L6565 QUASI-RESONANT SMPS CONTROLLER" DATASHEET

[2] "L6565 QUASI-RESONANT CONTROLLER" (AN1326)

[3] "25W QUASI-RESONANT FLYBACK CONVERTER FOR SET-TOP BOX APPLICATION USING THE L6565" (AN1376)

[4] "EVAL6565N, 30W AC-DC ADAPTER WITH THE L6565 QUASI-RESONANT PWM CONTROLLER" (AN1439)

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